- White Certificates Revisited - Extending the Basic Model

by
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Abstract

This paper deals with modeling the effects of introducing a market-based tool for improving end-users' efficiency in an energy market which is already regulated through a cap-and-trade system for green house gas emissions and a quota system meant to improve competitiveness of energy produced using renewable resources. In this model, distributors of energy are perceived as regional monopolists which are able to set the price of energy paid by consumers in their respective region. Once a White Certificate Trading Scheme (WCTS) is implemented, distributors are held responsible for achieving consumers' energy savings and energy efficiency targets set by regulation authorities. Results show that this way of regulating energy demand achieves its underlying objects of energy savings and energy efficiency solely at the expense of other goals such as the environmental efficiency of energy production, an effect described as pincers policy (Meran, Wittmann [8]). Moreover, in case of assuming a regular, i.e. falling, demand curve for energy, a price-induced reduction of demand in energy, if necessary, combined with buying white certificates will always be preferred by distributors over implementing incentive mechanisms to enforce consumers' investment in energy efficiency. Only if the properties of the model are varied, distributors will set an incentive greater than zero. However, in any case, without a reduction of the cap on emissions and an increase of the minimum quota of renewable energy, the introduction of WCTS will result in negative side effects on the environmental goals set on energy production and the amount of renewable energy produced. Therefore, implementing WCTS into a market which is already highly regulated cannot exactly be considered the icing on the cake of environmental policy. On the contrary, the amount and intensity of interdependencies and, hence, the countervailing effects of the various policy measures are intensified. Rather than proposing the introduction of yet another policy instrument, this paper opts for postulating the use of existing policy measures in a more effective way, in order to achieve all goals of environmental policy simultaneously.

Keywords: Energy Markets, Monopoly, Certificate Trading Scheme, White Certificates, Efficiency, Regulation, Market-based tool, *pincers policy*

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1. Introduction

As has already been shown by Montgomery, establishing markets for certificates can result in achieving a certain level of environmental quality efficiently, since social costs of pollution, assuming that they are feasibly calculable, have been accounted for, and hence, internalized (Montgomery, [9]). In trying to comply with the environmental demands postulated by the Kyoto-protocol, participating nations have established markets for permits (Sorrell, S., Sijm, J. [15]) controlling the emissions of various greenhouse gases (GHG), so called Brown Certificates. Moreover, means of improving the competitiveness of energy produced from renewable resources (Green Energy) have been undertaken in various counties, e.g. through the implementation of a Green Certificate Trading Scheme (Amundsen, E.S., Mortensen, J.B. [1]). However, as environmental goals have become increasingly ambitious, due to the fact that decision-makers are worried about the negative effects of a possible emission induced climate change on mankind, measures to reduce energy consumption of households have become the latest focus of attention (OECD, [11]). Hence, many people propose the establishment of a market for tradable permits gained by consumers of energy through investing in measures that will increase their respective energy efficiency (RWI (2006) [14]) and thereby reduce their demand for energy. In a few European Countries, like Great Britain, France, and Italy such a market-based tool has already been implemented (OECD, [11]), known as White Certificate Trading Scheme (WCTS). Due to reasons of practicability, distributors are to take part in WCTS, whereas households are only indirectly affected. Hence, if a distributors' consumers fail to fulfill a minimum requirement of energy efficiency measures which reduces their aggregate demand of energy to a certain target level set by authorities, the respective distributor needs to compensate for this gap by buying White Certificates. If a distributors' consumers surpass their requirements they thereby generate White Certificates which can be sold by their distributor (Bürger, [3]). This describes, in short, the workings of WCTS .

Despite all of the arguments in favor of WCTS stated in the present literature, the effects of introducing WCTS into a market system, which is already regulated through a cap-and-trade system for green house gas emissions and a quota system meant to improve competitiveness of energy produced using renewable resources, are less favorable than it might appear at first glance. Results show that this way of regulating energy demand achieves its underlying objects of energy savings and energy efficiency solely at the expense of other goals such as the environmental efficiency of energy production, an effect described as pincers policy (Meran, Wittmann [8]). Moreover, in case of assuming a regular, i.e. falling, demand curve for energy, a price-induced reduction of demand in energy, if necessary, combined with buying white certificates will always be preferred by distributors over implementing incentive mechanisms to enforce consumers' investment in energy efficiency. Only if the properties of the model are varied, distributors will set an incentive greater than zero. However, in any case, without a reduction of the cap on emissions and an increase of the minimum quota of renewable energy, the introduction of WCTS will result in negative side effects on the environmental goals set on energy production and the amount of renewable energy produced.Therefore, implementing WCTS into a market which is already highly regulated cannot be considered the icing on the cake of environmental policy. On the contrary, the amount and intensity of interdependencies and, hence, the countervailing effects of the various policy measures are intensified. Rather than proposing the introduction of yet another policy instrument, this paper opts for postulating the use of existing policy measures in a more effective way, in order to achieve the ambitious goals of environmental policy.

The paper is structured as follows: Before dealing with the implementation of WCTS the outline of the model is presented in section two. In section three, a total integration of end-users into WCTS is modeled. Section four deals with a possible incentive mechanism implemented by distributors to foster energy efficiency measures and, hence, increase energy savings of their consumers. The issue of possible measures of cost recovery by distributors is dealt with in section six. Section seven deals with the issue of setting a price cap on the price of energy and the effects of WCTS if implemented under these conditions. Section seven deals with relaxing the assumption that all distributors need to take part in WCTS. This constitutes a model of partial integration of distributors into WCTS. Section eight deals with the effects of policy measures which can be used instead of WCTS, such as the reduction of the cap on emissions and the increase in the quota of renewable energy. Section nine is comprised of some concluding remarks.

2. Basics of the Model[a]

First of all, in many countries, the energy market is characterized by imperfect competition, as it has already been stated in other papers (Fadeeva, [4]). However, In order to isolate the effects of WCTS, imperfect competition is assumed only on behalf of distributors of energy, which are perceived as regional monopolists, able to set the price of energy sold to their consumers. Producers of energy are supposed to operate under perfect competition. Hence, the setting can be described as follows: There are four groups that are involved in the market for energy: producers of energy produced using non-renewable resources (Brown Energy), producers of energy produced using renewable resources (Green Energy), distributors and end-users of energy. In the absence of WCTS markets for Green and Brown Certificates are already in place and assumed to be working properly. Sanctions for noncompliance with regulations, quotas or standards are assumed to be effective as well, so that there is no incentive to defect. Whereas the market for Brown Certificates is designed as a cap-and-trade market with maximum emissions set at level $\bar{e}$, the market for Green Certificates is based on a minimum quota system $\alpha\epsilon[0,1]$ of green energy in relation to total energy consumed and produced as seen in the paper of Amundsen and Mortensen (Amundsen, E.S., Mortensen, J.B. [1]). Now, properties and equations for each set of actors need to be defined.

The Supply Side[b]

This side of the market consists of producers of energy produced using non-renewable resources (Brown Energy)and producers of energy produced using renewable resources (Green Energy). The market is assumed to be perfectly competitive. Hence, all of them are assumed to be price-takers without market power.

[a]For details on calculations of the results presented in *all* following sections please refer to the denoted sections of the appendix.

[b]Modeling the supply side is based on Meran, Wittmann [8].

Green Energy:
The producers of Green Energy receive wholesale price q for each unit of Green Energy y produced as well as the price s of Green Certificates, which can be perceived as a market based subsidy paid by distributors. The costs of production $K(y)$, $K_y > 0, K_{yy} > 0$, are assumed to be relatively high. Hence, without subsidies and quota α Green Energy would not be able to compete successfully with Brown Energy. Profits are maximized according to

$$\max_y \; [(q+s)y - K(y)]$$

which results in the following first order condition (FOC):

$$K_y(y) = (q+s) \tag{1}$$

As a result, the amount of Green Energy produced can be expressed[c] by the following supply function:

$$\hat{y} = \hat{y}(q+s), \quad \hat{y}_q > 0 \tag{2}$$

Brown Energy:
The producers of Brown Energy face production costs $C(x)$, $C_x > 0, C_{xx} > 0$ as a function of units of energy produced x, which are assumed to be relatively low, compared to the costs of producing Green Energy. However, the production of energy using non-renewable resources is assumed to result in emissions of Greenhouse Gases, such as CO_2. Therefore, producers of Brown Energy incur additional costs as they need to comply with emission cap $\bar{e}$ set by regulation authorities and need to buy a certificate at price z for each unit (e) of CO_2 emitted. Additionally, they could also invest in abatement technologies I at price D which reduces the amount of emission per unit of energy produced (Montgomery [9]). Emission can, thereby, be expressed as a function of amount of energy produced and investment in abatement:

$$e = e(x, I), \quad e_x > 0 \quad \text{and} \quad e_I < 0 \tag{3}$$

It is assumed that emissions rise as x rises and fall as I rises. In both cases, diminishing marginal effects exist, i.e. $e_x > 0, e_{xx} > 0$, $e_I < 0, e_{II} > 0$. Moreover, it is assumed that the marginal impact on emissions through an increase in output diminishes as I rises, i.e. $e_{xI} = e_{Ix} < 0$. Finally, $e(x, I)$ is convex and, hence, producers' resulting profit function is concave. Profits are maximized according to

$$\max_{x,I} \; [qx - C(x) - ze(x, I) - ID]$$

which results in the following FOCs:

$$q = C_x(x) + ze_x(x, I) \tag{4}$$

$$D = -ze_I(x, I) \tag{5}$$

[c]appendix I.1, equation (51)

As a result, the amount of Brown Energy produced and the amount of investment made can be expressed as a function of prices q, z, i.e.

$$\hat{x} = \hat{x}(q, z) \quad \text{and} \quad \hat{I} = \hat{I}(q, z) \tag{6}$$

since $D = \bar{D}$ is held constant. In order to analyze the effects on $\hat{x}$ and $\hat{I}$ with respect to changes in prices q and z, equations (4) and (5) are used. Changes in q render the following results: As it is shown in in the appendix [d], both $\hat{x}$ and $\hat{I}$ rise in q, i.e. $\hat{x}_q > 0$ and $\hat{I}_q > 0$. Changes in z result in the subsequent effects: As it is shown in in the appendix [e], while $\hat{x}$ is negatively correlated to z, $\hat{I}$ increases if z rises, i.e. $\hat{x}_z < 0$ and $\hat{I}_z > 0$. To summarize

$$\hat{x}_q > 0, \quad \hat{I}_q > 0, \quad \hat{x}_z < 0, \quad \hat{I}_z > 0 \tag{7}$$

Subsequently, we need to determine the reaction of the emission function, i.e. $\hat{e}(q, z) = e(\hat{x}, \hat{I})$, to possible changes in q and z:

$$\hat{e}(q, z) = e(\hat{x}(q, z), \hat{I}(q, z)) \tag{8}$$

From equations (3) and (7) it follows that

$$\hat{e}_z = e_x \hat{x}_z + e_I \hat{I}_z < 0 \tag{9}$$

The reaction of $\hat{e}$ to an increase in q is ambiguous. This follows from

$$\hat{e}_q = e_x \hat{x}_q + e_I \hat{I}_q \tag{10}$$

and equation (7) to (8). In the following, it is assumed that $\hat{e}_q > 0$, since, as energy wholesale price increases, production rises and, therefore, emissions increase, as well. The countervailing effect of an increase in abatement investment (I) does not compensate for an increase in emissions due to an increase in the production of Brown Energy x.

The Demand Side
This side of the market consists of distributors and end-users of energy.

End-users:[f]
We assume a strictly concave utility function U, which depends on the amount of energy consumed v at price p and the amount of investment i in energy efficiency at price d. The utility function U can be perceived as a reduced form of a traditional utility function and a household production function (Wirl [17]). In the absence of White Certificates, the utility of a representative household of region j is maximized according to

$$\max_{v_j, i_j} \; [U(v_j, i_j) - p_j v_j - i_j d]$$

[d] appendix I.1, equation (52)
[e] appendix I.1, equation (55)
[f] Modeling End-users is based on Meran, Wittmann [8].

which results in the following FOCs:

$$p_j = U_{v_j}(v_j, i_j) \quad \text{and} \quad d = U_{i_j}(v_j, i_j) \tag{11}$$

The equilibrium amount of energy demanded $\hat{v}_j$ and the amount of investment chosen $\hat{i}_j$ can be expressed as a function of market price p_j

$$\hat{v}_j = \hat{v}_j(p_j) \qquad\qquad \hat{i}_j = \hat{i}(p_j)$$

as we assume $d = \bar{d}$ to be constant.
Results regarding changes in p_j are as follows: While $\hat{v}_j$ is always negatively correlated regarding changes in p_j, $\hat{i}_j$ is positively (negatively) related to p_j, if $\hat{i}_j$ and $\hat{v}_j$ are substitutes (complements). Considering changes in d we obtain the following results as shown in the appendix [g]: While $\hat{i}_j$ is always negatively correlated regarding changes in d, $\hat{v}_j$ is positively (negatively) related to d, if $\hat{i}_j$ and $\hat{v}_j$ are substitutes (complements). In the following it is assumed that energy consumption and investment in energy efficiency are substitutes.

Distributors:
The distributors buy energy from producers at wholesale price q and sell it at market price p, i.e. $p > q$. They are not able to influence wholesale prices, as they are seen as relatively small regional monopolists. Nonetheless, distributor j, $\forall j = 1, ..., n$, is able to set the market price p_j of its region j and to maximize its profits accordingly. Distributors need to ensure that the amount of Green Energy satisfies quota α and, hence, are forced to buy the respective amount of Green Certificates at price s. As Brown Energy is assumed to be relatively cheaper, distributors demand the minimum amount of Green Energy, $y = \alpha(x+y)$ (minimum quota system), to satisfy the demand in their respective region j. The total amount of energy demanded is denoted by $\hat{v} = \hat{x} + \hat{y}$ (market equilibrium), whereas $\hat{v} = \Sigma_{i=1}^{n} \hat{v}_j$. Also, distributors incur network costs $c^n(v)$, with $c_v^n(v) > 0, c_{vv}^n(v) > 0$, which depend on the amount of energy distributed. Hence, each distributor j maximizes its profits according to

$$\max_{p_j} (p_j - q - \alpha s)\hat{v}_j(p_j) - c^n(\hat{v}_j) \tag{12}$$

Utilizing the market equilibrium condition $\hat{v}_j = \hat{x}_j + \hat{y}_j$ we arrive at

$$\hat{v}_j + (p_j - q - \alpha s - c_{v_j}^n)\frac{\partial \hat{v}_j}{\partial p_j} = 0 \tag{13}$$

which yields

$$p_j + \frac{\hat{v}_j(p_j)}{\frac{\partial \hat{v}_j(p_j)}{\partial p_j}} = q + \alpha s + c_{v_j}^n, \ \forall j = 1, .., n. \tag{14}$$

Distributors will set marginal revenue equal to marginal cost and choose prices p_j such that they are facing the profit maximizing, unitary elastic, section of the demand curve, i.e. $|\epsilon(p_j)| = 1$, i.e. $|\epsilon(p_j)| = \frac{p_j}{\hat{v}_j}\frac{\partial \hat{v}_j}{\partial p_j}$, and $\hat{v}_j(1 + |\epsilon(p_j)|) = q + \alpha s + c_{v_j}^n$. Now, we are able to move on to the core of our model.

[g] Using equation (11), and appendix I.2 equation (62)

3. **Total Integration of End-users into WCTS**

Taking all assumptions and previously stated settings into account, we can determine the equilibrium conditions for the energy markets and the market for Brown Certificates through equations(15) to (17):

$$(1-\alpha)\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{x}(q,z) = 0 \tag{15}$$

$$\alpha\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{y}(q+s) = 0 \tag{16}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{17}$$

and equations (14) determining equilibrium prices p_j for every region j.

Solving these equations, results in a set of equilibrium prices in the absence of WCTS, i.e. $q^o, z^o, s^o > 0$, and $p_j^o > 0$.

The introduction of an effective WCTS into the market system by establishing a maximum quantity of energy demanded $\bar{v}_j$ for every region j, results in the following equations, taking into account that $\bar{v}_j < \hat{v}_j(p_j^o)$:

$$(1-\alpha)\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{x}(q,z) = 0 \tag{18}$$

$$\alpha\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{y}(q+s) = 0 \tag{19}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{20}$$

$$\Sigma_{j=1}^{n}\bar{v}_j\ -\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) = 0 \tag{21}$$

Equilibrium market prices p_j is now determined through a slight modification of equation (12) taking into account that for every unit of energy consumed more (less) than $\bar{v}_j$ a White Certificate w has to be bought (is generated)

$$\max_{p_j}(p_j - q - \alpha s)\hat{v}_j(p_j) - c^n(\hat{v}_j) + w(\bar{v}_j - \hat{v}_j(p_j)) \tag{22}$$

which results in the following equilibrium condition for market prices p_j

$$p_j + \frac{\hat{v}_j(p_j)}{\frac{\partial \hat{v}_j(p_j)}{\partial p_j}} = q + \alpha s + c^n_{v_j} + w. \tag{23}$$

Price w of white certificates is thereby perceived as an additional marginal cost of energy production. Through the introduction of WCTS energy producers are forced to adapt the goal of forcing demand to become equal to or less than $\bar{v}_j$. Naturally, they do not have to buy w for every unit of energy distributed, however, every unit of energy distributed less (more) than $\bar{v}_j$ would generate (cost) w but they would also forgo (gain) p_j. Hence, w can be seen as a real cost for every unit of energy distributed, where $\hat{v}_j > \bar{v}_j$, and as a opportunity cost for every unit of energy distributed, where $\hat{v}_j < \bar{v}_j$.

The solution obtained by these equations leads to equilibrium prices defined as $p_j^w, q^w, s^w, z^w > 0$, and $w > 0$.

Proposition 1 *The introduction of a WCTS leads to an increase of $\hat{i}_j$ and a decrease of $\hat{I}$ and of the amount renewable energy supplied $\hat{y}$.*

Proof: Let us begin with the latter statement. Since, by equation (8), $\bar{e} = \hat{e}(q,z) = e((1-\alpha)\bar{v}, \hat{I}(q,z))$, where $\bar{v} = \Sigma_{j=1}^{n}\bar{v_j}$, it follows that $\hat{I}_{\bar{v}} > 0$:

$$\hat{I}_{\bar{v}} = \frac{-(1-\alpha)e_x}{e_I} \ > \ 0 \tag{24}$$

The equilibrium amount of renewable energy supplied is characterized by equation (2), i.e. $\hat{y}(q+s)$. Therefore, $\hat{y}_{\bar{v}} = y_1(\frac{\partial \hat{q}}{\partial \bar{v}} + \frac{\partial \hat{s}}{\partial \bar{v}}) > 0$[h]. As the amount of energy consumed is reduced, i.e. $\bar{v} = \Sigma_{j=1}^{n}\bar{v_j} = \Sigma_{j=1}^{n}\hat{v}(p_j^w) < \Sigma_{j=1}^{n}\hat{v}(p_j^o)$, the amount of renewable energy supplied is reduced as well.
In order to prove the former assertion, we differentiate equation (11) with respect to $\bar{v}$ which yields

$$\frac{\partial \hat{i}}{\partial \bar{v}} = -\frac{U_{iv}}{U_{ii}} < 0$$

Applying some comparative statics to equations (18) to (23) [i] we arrive at

$$p_{\bar{v}}^w < 0, \ \ q_{\bar{v}}^w > 0, \ \ s_{\bar{v}}^w \gtreqless 0, \ \ (q_{\bar{v}}^w + \alpha s_{\bar{v}}^w) > 0, \ \ z_{\bar{v}}^w > 0, \ \text{ and } \ w_{\bar{v}} < 0$$

Now, all of the effects of implementing WCTS can be inferred. In order to increase end-users' energy savings and energy efficiency regulation authorities set $\bar{v} = \Sigma_{j=1}^{n}\bar{v_j} < \Sigma_{j=1}^{n}\hat{v}(p_j^o)$. As sanctions are supposed to be working properly, distributors will force end-users to comply with $\bar{v}$ through a price-induced reduction of demand in energy. Depending on region j's households utility function, the reduction in demand will determine whether distributor j becomes a net seller or a net buyer of White Certificates, or simply meets $\bar{v_j} = \hat{v}_j(p_j^w)$. Moreover, consumers will substitute energy consumption with investment in energy efficiency as its price as also become relatively cheaper compared to the price of energy, i.e. $\frac{\bar{d}}{p_j^w} < \frac{\bar{d}}{p_j^o}$. But that is not the end of the story. The production of renewable energy $\hat{y}$ decreases. As the production of Brown Energy $\hat{x}$ and the price of Brown Certificates z decreases, along with the amount of investment in abatement technology $\hat{I}$. Hence, the reduced amount of Brown Energy $\hat{x}$ is produced using less investment in abatement $\hat{I}\downarrow$ and at a lower price for Brown Certificates $z\downarrow$, which results in an increase in emissions per unit of energy $[\frac{\hat{e}(q,z)\uparrow}{\hat{x}(q,z)\downarrow}] \Uparrow$. As a result, the environmental efficiency in energy production is reduced. From an environmental point of view, this is clearly a negative effect.

4. **Implementing an Incentive Mechanism to further stimulate Households' investment in Energy Efficiency**
It has also been suggested, that distributors design an incentive mechanism to further stimulate households' investment in energy efficiency, e.g. wall insulation or improvement of heating control (Fadeeva, [4]). This incentive can be perceived as a market-based subsidy of energy efficiency measures. Instead of having to pay $\bar{d}$ for every unit of i_j, households of region j now only pay $(1-\sigma_j)\bar{d}$, where $0 \leq \sigma_j \leq 1$, while the respective distributor j provides $\sigma_j \bar{d}$ for every unit of i_j acquired. In this case, distributors are assumed to have perfect information about households' Utility function and their utility maximizing first order conditions. Therefore, they are

[h] Appendix II.2
[i] appendix II.1 and II.2

able to predict households' reaction to energy prices p_j and incentive σ_j. Like a Stackelberg leader, distributor j now chooses the profit maximizing level of p_j and σ_j, given $\bar{v}_j$ accordingly. End-users' utility maximizing conditions, equations (11) are therefore modified as follows.

$$\max_{v_j, i_j} \ [U(v_j, i_j) - p_j v_j - (1-\sigma_j) i_j \bar{d}]$$

which results in the following FOCs:

$$p_j = U_{v_j}(v_j, i_j) \quad \text{and} \quad (1-\sigma_j)\bar{d} = U_{i_j}(v_j, i_j) \tag{25}$$

The equilibrium amount of energy demanded $\hat{v}_j$ and the amount of investment chosen $\hat{i_j}$ can be expressed as a function of market prices p_j and σ_j which results in

$$\hat{v}_j = \hat{v}_j(p_j, \sigma_j) \qquad\qquad \hat{i_j} = \hat{i}_j(p_j, \sigma_j)$$

While equations (18) to (21) remain unchanged, equations (22) are modified.

$$\max_{p_j, \sigma_j} \ (p_j - q - \alpha s)\hat{v}_j(p_j, \sigma_j) - c^n(\hat{v}_j(p_j, \sigma_j)) + w(\bar{v}_j - \hat{v}_j(p_j, \sigma_j)) - \sigma_j \ \bar{d} \ \hat{i}(p_j, \sigma_j) \tag{26}$$

Proposition 2 *In equilibrium, distributor j will set the incentive $\hat{\sigma}_j = 0$ according to Kuhn-Tucker conditions.*

Proof:[j] Regarding the FOCs' with respect to σ_j lead to the follows effects: As $(p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d} \ \hat{i} - \bar{d} \ \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j} \ < \ 0$ it becomes clear that

$$0 \neq (p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d} \ \hat{i} - \bar{d} \ \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j} \tag{27}$$

and hence the condition $\sigma_j[(p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d} \ \hat{i} - \bar{d} \ \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}] = 0$ can only hold true if $\sigma_j = 0$.

To sum it up, in this setting a distributor will never implement an incentive mechanism as a market-based subsidy to increase households' investment in energy efficiency. After distributor j has set $\hat{\sigma}_j = 0$, the remaining set of equations equals the model depicted in the previous section, i.e. (18) to (21), including both positive and negative effects resulting from the implementation of WCTS. However, these results imply that, aside from the assumption of perfect information, energy demand correlates negatively to energy prices and that there are no goals or regulations regarding the level of energy prices. As will be seen in section seven of this paper, if the latter condition is changed, results differ.

5. Cost Recovery

Another issue that needs to be looked at, is the question of cost recovery on behalf of distributors. In reality, distributors are eligible to redeem costs of WCTS by increasing the price of energy - with or without limits - or, as known from the Italian WCTS, there exists a fund out of which distributors receive redemption for costs incurred through their efforts in reducing households' demand in energy and increase in energy efficiency (Quirion [12]). Assuming that for every White Certificate generated distributor j receives an amount b, i.e. $b > 0$ and $b(\bar{v}_j - \hat{v}_j(p^w))$ if $\bar{v}_j > \hat{v}_j(p^w)$, and $b = 0$ if $\bar{v}_j \leq \hat{v}_j(p^w)$.

[j] For details on calculations please refer to appendix IV.

Corollary 1 *Every increase in b will be offset by an equivalent decrease of the price in White Certificates w, i.e.* $\frac{\partial w}{\partial b} = -1$.

Proof: Both instruments, White Certificates through price w and the redemption fund through payment b, target the same section of the market. Distributor j maximizes its profit according to a modification of equations (22) resulting in equations (69) and FOCs

$$p_j + \frac{\hat{v}_j}{\frac{\partial \hat{v}_j}{\partial p_j}} = q + \alpha s + c^n_{v_j} + (w + b). \tag{28}$$

whereas the remaining equilibrium conditions, i.e. equations (18) to (21) are unchanged.

$$(1-\alpha)\ \Sigma_{j=1}^n \hat{v}_j(p_j) - \ \hat{x}(q,z) = 0 \tag{29}$$

$$\alpha\ \Sigma_{j=1}^n \hat{v}_j(p_j) - \ \hat{y}(q+s) = 0 \tag{30}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{31}$$

$$\Sigma_{j=1}^n \bar{v}_j\ -\ \Sigma_{j=1}^n \hat{v}_j(p_j) = 0 \tag{32}$$

Equilibrium conditions render prices $p_j^b, s_j^b, q_j^b, z_j^b$, and $w > 0$. As $b > 0$, changes in the price of White Certificates are $\frac{\partial w}{\partial b} = -1$, whereas $\frac{\partial p_j}{\partial b}, \frac{\partial q}{\partial b}, \frac{\partial s}{\partial b}, \frac{\partial z}{\partial b} = 0$ [k].

This kind of offsetting effect of two policy instruments, which simultaneously target an identical section of the market, has already been referred to in Heilmann [5]. The remaining results are therefore identical to those witnessed in section three.

6. Price Caps

So far, it has been the case, that there is no upper limit on the price set by distributor j. If it were the case that after introducing WCST distributors were only allowed increase price by a certain percentage μ, i.e. $0 \leq \mu < 1$, such that $p_j^w = (1+\mu)\ p_j^o$, the price-induced reduction of demand might not suffice to meet the requirement of $\bar{v}_j \geq \hat{v}_j(p_j^w)$. Market equilibrium is defined by the following equations

$$(1-\alpha)\ \Sigma_{j=1}^n \hat{v}_j(p_j) - \ \hat{x}(q,z) = 0 \tag{33}$$

$$\alpha\ \Sigma_{j=1}^n \hat{v}_j(p_j) - \ \hat{y}(q+s) = 0 \tag{34}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{35}$$

$$\Sigma_{j=1}^n \bar{v}_j\ -\ \Sigma_{j=1}^n \hat{v}_j(p_j) = 0 \tag{36}$$

and the profit maximizing condition regarding distributor j

$$\max_{p_j,\sigma_j} (p_j - q - \alpha s)\hat{v}_j(p_j,\sigma_j) - c^n(\hat{v}_j(p_j,\sigma_j)) + w\ (\bar{v}_j - \hat{v}_j(p_j,\sigma_j)) + t\ (\bar{v}_j - \hat{v}_j(p_j,\sigma_j)) - \sigma_j\ \bar{d}\ \hat{i}(p_j,\sigma_j) \tag{37}$$

subject to $p_j^w \leq (1+\mu)\ p_j^o$.

Proposition 3 *If the increase in price does not suffice to match* $\bar{v}_j \geq \hat{v}_j(p_j^w)$*, the price of White certificates will become extremely high, as no one, or only few distributors are able to generate any. Assuming that per unit sanctions t for noncompliance with* $\bar{v}_j$ *are working properly and are set at a very high lever, distributors will set* $\hat{\sigma}_j > 0$.

[k] for details on calculations please refer to appendix V.

Proof: As the maximum possible price is $p_j^{\bar{w}} = (1+\mu)\ p_j^o$ which results in $\bar{v}_j < \hat{v}_j(p_j^w)$. Therefore, the only way to reduce the amount of energy demanded is setting $\sigma_j > 0$ as the amount of energy demanded correlates negatively to changes in σ_j, i.e. $\frac{\partial \hat{v}_j}{\sigma_j} < 0$. As per unit sanction t and the price of White Certificates w are supposed to be extremely high and prices $p_j^{\bar{w}}$ are fixed, the FOCs of equations (37) with respect to σ_j are now able to satisfy the equations

$$0 = (p_j - q - \alpha s - c^n_{v_j} - w - t)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d}\ \hat{i} - \bar{d}\ \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j} \tag{38}$$

Therefore, the condition $\sigma_j[(p_j - q - \alpha s - c^n_{v_j} - w - t)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d}\ \hat{i} - \bar{d}\ \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}] = 0$ holds true, even if $\sigma_j > 0$.

Through setting $\sigma_j > 0$, distributor j reduces its consumers demand for energy, i.e. $\hat{v}_j(p_j^{\bar{w}}, \sigma_j) < \hat{v}_j(p_j^{\bar{w}}), \forall\ \sigma_j > 0$. However, the question remains, how high the incentive will be set.

Corollary 2 *Distributors j will utilize an incentive mechanism to improve energy efficiency, and thereby reduce the amount of energy demanded, as long as its costs are less or equal to per unit sanctions of noncompliance with* $\bar{v}_j$.

Proof: In equilibrium, distributor j will be indifferent between the per unit sanction t, assuming that $t < w$, or the costs of the incentive mechanism

$$t\ (\bar{v}_j - \hat{v}_j(p_j, \sigma_j)) = \sigma_j\ \bar{d}\ \hat{i}(p_j, \sigma_j) \tag{39}$$

which results in an equilibrium level of incentive mechanism $\hat{\sigma}_j$

$$\hat{\sigma}_j = -[t\frac{\partial \hat{v}_j}{\partial \hat{\sigma}_j} + (\hat{i}_j + \frac{\partial \hat{i}_j}{\partial \hat{\sigma}_j})\bar{d}] > 0 \tag{40}$$

In case of price caps, distributors will utilize the incentive mechanism to increase end-users energy efficiency. As a result, end-users' investment in energy efficiency rises, as $\frac{\hat{i}_j}{\sigma_j} > 0$, and the amount of energy demanded decreases[1], as $\frac{\hat{v}_j}{\sigma_j} < 0$. However, the negative effects of introducing WCTS into the market regarding investment in abatement ($\hat{I}$) and the amount of Green Energy produced ($\hat{y}$) are still present. Hence, even if the incentive mechanism is implemented, without a increase in the minimum quota of Green Energy demanded, α, and a decrease in the cap on emissions, $\bar{e}$, WCTS has a negative impact on the goals of environmental policy previously stated.

7. Partial integration of Distributors into WCTS

In reality, not all distributors of energy are forced to take part if WCTS is implemented. Only distributors whose number of clients, i.e. number of households supplied, surpasses a certain threshold set by regulation authorities have to comply (Oikonomou [12]). Therefore, it is assumed that only a number of K distributors, i.e. $K \subset n$, with $K \neq \emptyset$, are large enough to take part in WCTS while the remaining $n - K$ distributors do not meet the threshold requirement. Before introducing WCTS all distributors were faced with identical profit maximizing conditions. Now, a representative distributer k of group K, i.e. $k\ \epsilon\ K$, is setting its profit maximizing price p_k according to equation (23) while a representative

[1]Appendix V.1, equations (73) and (74).

distributor j of group (n-K), i.e. $j \epsilon (n-K)$, utilizes equation (14) to set price p_j. Hence, market equilibrium is defined by modifying of equations (18) to (21)

$$(1-\alpha)\ (\Sigma_{k=1}^{K}\hat{v_k}(p_k) + \Sigma_{j=1}^{(n-K)}\hat{v_j}(p_j)) -\ \hat{x}(q,z) = 0 \tag{41}$$

$$\alpha\ (\Sigma_{k=1}^{K}\hat{v_k}(p_k) + \Sigma_{j=1}^{(n-K)}\hat{v_j}(p_j)) -\ \hat{y}(q+s) = 0 \tag{42}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{43}$$

$$\Sigma_{j=1}^{K}\bar{v_k}\ -\ \Sigma_{j=1}^{K}\hat{v_k}(p_k) = 0 \tag{44}$$

Proposition 4 *In the absence of limits for energy prices, prices p_k will always be higher than p_j* [m]*, as distributor k has to account for the opportunity cost w of every unit of energy supplied, whereas distributor j does not have to.*

Proof: Distributor k will set price p_k according to

$$p_k + \frac{\hat{v_j}}{\frac{\partial \hat{v_j}}{\partial p_j}} = q + \alpha s + c_{v_j}^{n} + w \tag{45}$$

which results in the profit maximizing condition $|\epsilon(p_k)| = \frac{p_k}{\hat{v_k}}\frac{\partial \hat{v_k}}{\partial p_k} = 1$, and $\hat{v_k}(1+|\epsilon(p_k)|) = q + \alpha s + c_{v_k}^{n} + w$.
While distributor j will set price p_j according to

$$p_j + \frac{\hat{v_j}}{\frac{\partial \hat{v_j}}{\partial p_j}} = q + \alpha s + c_{v_j}^{n} \tag{46}$$

which results in the profit maximizing condition $|\epsilon(p_j)| = \frac{p_j}{\hat{v_j}}\frac{\partial \hat{v_j}}{\partial p_j} = 1$, and $\hat{v_j}(1+|\epsilon(p_j)|) = q+\alpha s+c_{\hat{v_j}}^{n}$. Representative households j and k are characterized by equation (11). Applying some comparative statics to equations (41) to (21) and equation (45) to (46) results in

$$p_{k\ \bar{v}}^{w} < 0,\ \ q_{\bar{v}}^{w} > 0,\ \ s_{\bar{v}}^{w} \gtrless 0,\ \ (q_{\bar{v}}^{w} + \alpha s_{\bar{v}}^{w}) > 0,\ \ z_{\bar{v}}^{w} > 0,\ \ w_{\bar{v}} < 0, \text{ and } p_{j\ \bar{v}}^{w} > 0$$

As price p_k set by the regulated distributor rises, demand of household k will decrease. However, as wholesale prices decrease, the effect on the price set by distributor j is exactly opposite to that. As p_j decreases, demand of household j increases.

The question that remains is, how large the relative changes in demand are and whether the two contrary effects offset each other or not.

Lemma 1 *The increase in demand in $\hat{v}_j(p_j^w)$ does not completely offset the decrease in demand caused by implementing $\bar{v} = \Sigma_{j=1}^{K}\bar{v_k}$, i.e. $\frac{\partial \hat{v}_j(p_j^w)}{\partial \bar{v}} < -1$.*

Proof: Please refer to appendix VI.3

The effects of implementing WCTS in case of partial integration are can certainly be considered ambiguous. Energy demand of households supplied by regulated distributors will decrease, and cause investment in energy efficiency to increase, as its relative price is reduced. Energy demand of households supplied by unregulated distributors will increase, and cause investment in energy efficiency to decrease, as its relative price is raised. The

[m]It is assumed that households are bound to be supplied by their regional supplier.

combined effect on wholesale prices and amount of energy produced depends on whether $\frac{\partial \hat{v}_j(p_j^w)}{\partial \bar{v}} \lesseqgtr -1$. In case of this model, there is no completely offsetting effect, as $\frac{\partial \hat{v}_j(p_j^w)}{\partial \bar{v}} < -1$, however, implementing WCTS renders results which are far from what can be considered a satisfying second-best solution from an environmental point of view.

8. Is less still more?

As the implementation of WCTS results in a negative impact on environmental policy measures present in this model, an alternative is proposed. Instead of introducing yet another policy measure, regulation authorities might achieve a better outcome by using the policy instruments already prevalent in the market, such as the cap on emissions, $\bar{e}$. In equilibrium, equations (14), and (15) to (17) remain unchanged, i.e.

$$(1-\alpha)\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{x}(q,z) = 0 \tag{47}$$

$$\alpha\ \Sigma_{j=1}^{n}\hat{v}_j(p_j) - \ \hat{y}(q+s) = 0 \tag{48}$$

$$\bar{e}\ -\ \hat{e}(q,z) = 0 \tag{49}$$

and

$$p_j + \frac{\hat{v}_j(p_j)}{\frac{\partial \hat{v}_j(p_j)}{\partial p_j}} = q + \alpha s + c_{v_j}^n,\ \forall j = 1,..,n. \tag{50}$$

Proposition 5 *As $\bar{e}$ is reduced, emissions become more costly due to an increase in scarcity. Therefore, investment in abatement (I) will increase. Households' investment in energy efficiency (i) increases as well, as the wholesale price, and along with it the market price, of energy increases.*

Proof: Firstly, households' reaction (i) to a reduction in the cap of emission needs to defined, as well as the effect of the latter on investment in abatement (I). Comparative statics [n] with respect to $\bar{e}$ yields, that investment in energy efficiency increases, i.e. $\hat{i}_{j\bar{e}} < 0$. Secondly, Brown Energy producers' reaction to changes in $\bar{e}$ is analyzed [o]. As shown in the appendix, investment in abatement (I) increases as $\bar{e}$ is reduced, $\hat{I}_{\bar{e}} < 0$.

Results of an reduction in the cap of emissions are clearly favorable. The only negative effect is the reduction in production of renewable energy, due to an overall decrease in energy demanded, i.e. $\frac{\partial \hat{v}_j}{\partial \bar{e}} > 0$. There are two remedies to dispense with this problem. First, regulation authorities could increase the minimum quota of renewable energy demanded, α. Second, the problem is solved by the market itself, if the cap on emissions raises the price of Brown Energy to a such a level that the price of Green Energy is equal or even less than that. In that case, distributors would be either indifferent between the two types of energy or even prefer Green Energy over Brown Energy, as is has become relatively cheaper. If there are no relevant restrictions on the capacity of production of Green Energy, both alternatives present a possible and, which is even more important, a environmentally favorable solution to the problem in question.

[n]appendix VIII.3, equation (82)
[o]appendix VIII.3, equation (81)

9. Conclusions

In general, assuming distributors to be monopolists can be considered a relatively realistic setting, looking at the history of various European Countries (Fadeeva, [4]). Other problems of environmental policy such as negative direct and indirect effects between policy instruments (Heilmann, [5]) are displayed in this model, as well. Some experts assume energy demand to be relatively inelastic to price changes (Bertoldi et. al. [2]) and propose WCTS as a possible solution to successfully deal with this problem. However, in the setting without price caps, WCTS is just another way to increase the relative price of energy. As a result, the effect of a possible increase in energy prices due to the implementation of WCTS will have no effect regarding end-users' energy efficiency or energy consumption, if the latter really reacted inelastic to price. If there are restrictions on energy prices, e.g. price caps, an incentive mechanism created by distributors to increase energy efficiency of end-users will pose an effective measure to reduce energy demand, as long as the per unit sanctions of noncompliance on behalf of distributors are greater or equal to the cost of the incentive mechanism. However, the negative effects of the introduction of WCTS, regarding the amount of Green Energy produced and the level of investment in abatement technology, remain prevalent and have to be dealt with. Therefore, even in this particular case the implementation of WCTS creates additional problems through its effect on the environmental policy measures already in place. To sum it up, in this model, a very sensible and effective way to achieve all of the environmental goals mentioned above is to keep things simple. Instead of introducing another certificate system the policy measures and the markets already in place need to be used to accomplish additional goals. Through a reduction in the cap of emissions - and, if necessary, a raise in the quota for renewable energy - all goals can successfully, efficiently, and effectively be achieved without having to incur any negative side-effects or additional costs on behalf of regulation authorities. Therefore, even in the case of trying to accomplish one more object through environmental policy, regarding the given circumstances, implementing less measures really seems to be the better deal.

10. **Appendix**

I. Basics of the Model

I.1 The Supply Side

This side of the market consists of producers of energy produced using non-renewable resources (Brown Energy)and producers of energy produced using renewable resources (Green Energy).

Green Energy:

$$K_y(y) = q + s, \quad K_{yy}\hat{y}_q = 1, \quad \hat{y}_q = \frac{1}{K_{yy}} > 0 \tag{51}$$

Brown Energy:
Changes in q:

$$\Delta \begin{pmatrix} \hat{x}_q \\ \hat{I}_q \end{pmatrix} = \begin{pmatrix} -1 \\ 0 \end{pmatrix} \tag{52}$$

where $\Delta = \begin{pmatrix} -(C_{xx} + ze_{xx}) & -ze_{xI} \\ -ze_{Ix} & -ze_{II} \end{pmatrix}$. Assuming concavity it follows that

$$|\Delta| = z(e_{II}(ze_{xx} + K_{xx}) - ze_{xI}^2) > 0 \tag{53}$$

From (52) it follows

$$\hat{x}_q = \frac{ze_{II}}{|\Delta|} > 0 \quad \hat{I}_q = \frac{-ze_{xI}}{|\Delta|} > 0 \tag{54}$$

Changes in z:

$$\Delta \begin{pmatrix} \hat{x}_z \\ \hat{I}_z \end{pmatrix} = \begin{pmatrix} e_x \\ e_I \end{pmatrix} \tag{55}$$

From (53) and (55) it follows

$$\hat{x}_z = \frac{z(e_I e_{xI} - e_x e_{II})}{|\Delta|} < 0 \quad \hat{I}_z = \frac{z(e_x e_{Ix} - e_I(\frac{C_{xx}}{z} + e_{xx}))}{|\Delta|} > 0 \tag{56}$$

I.2 The Demand Side

This side of the market consists of distributors and end-users of energy.

End-users:
Changes in p:

$$\Omega \begin{pmatrix} \hat{v}_p \\ \hat{i}_p \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix} \tag{57}$$

where $\Omega = \begin{pmatrix} U_{vv} & U_{vi} \\ U_{iv} & U_{ii} \end{pmatrix}$.
By the assumption of concavity it follows that

$$|\Omega| = U_{vv}U_{ii} - U_{vi}^2 > 0 \tag{58}$$

From (57) and (58) it follows that

$$\hat{v}_p = \frac{U_{ii}}{|\Omega|} < 0 \tag{59}$$

$$\hat{i}_p = -\frac{U_{iv}}{|\Omega|} > 0 \quad \text{, if i and v are substitutes and} \tag{60}$$

$$\hat{i}_p = -\frac{U_{iv}}{|\Omega|} < 0 \quad \text{, if i and v are complements} \tag{61}$$

Changes in d:

$$\Omega \begin{pmatrix} \hat{v}_d \\ \hat{i}_d \end{pmatrix} = \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{62}$$

$$\hat{i}_d = \frac{U_{vv}}{|\Omega|} < 0 \tag{63}$$

$$\hat{v}_d = -\frac{U_{iv}}{|\Omega|} < 0 \tag{64}$$

, if i and v are complements

$$\hat{v}_d = -\frac{U_{iv}}{|\Omega|} > 0 \tag{65}$$

, if i and v are substitutes.

In the following, it is assumed that investment in energy efficiency and energy consumption are substitutes.

II. Total Integration of End-users into WCTS

II.1 Changes in prices p_j with respect to $\bar{v}_j$ are derived according to equation (21):

$1 \; - \; \Sigma_{j=1}^{n} \hat{v}_{j_{p_j}} \frac{\partial p}{\partial \bar{v}_j} = 0$

which results in

$$\Sigma_{j=1}^{n} \frac{\partial p}{\partial \bar{v}_j} = \Sigma_{j=1}^{n} \frac{1}{\hat{v}_{j_{p_j}}} < 0 \tag{66}$$

From (18) to (20) we can derive the effects of changes in $\bar{v}$ on prices q, s and z:

$$\Theta \begin{pmatrix} q_{\bar{v}}^{w} \\ s_{\bar{v}}^{w} \\ z_{\bar{v}}^{w} \end{pmatrix} = \begin{pmatrix} \alpha \Sigma_{j=1}^{n} \hat{v}_{j_{p_j}} \frac{\partial p}{\partial \bar{v}_j} \\ (1-\alpha) \Sigma_{j=1}^{n} \hat{v}_{j_{p_j}} \frac{\partial p}{\partial \bar{v}_j} \\ 0 \end{pmatrix} \tag{67}$$

where $\Theta = \begin{pmatrix} \hat{y}_q & \hat{y}_q & 0 \\ \hat{x}_q & 0 & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix}$.

Due to assumption of concavity and due to equations (3), (7), and (51), it can be inferred that

$$|\Theta| = -\hat{y}_q(\hat{x}_q \hat{e}_z - \hat{x}_z \hat{e}_q) > 0 \tag{68}$$

II.2 From (67) and (68) it follows that

$q_{\bar{v}}^{w} = \frac{-(1-\alpha)\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}}\frac{\partial p}{\partial \bar{v}_j}\hat{x}_q\hat{e}_z}{|\Theta|} > 0$

$s_{\bar{v}}^{w} = \frac{\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}}\frac{\partial p}{\partial \bar{v}_j}[\hat{e}_z((1-\alpha)\hat{y}_q-\alpha\hat{x}_q)-\hat{x}_z\hat{e}_q]}{|\Theta|} > 0$[p]

$z_{\bar{v}}^{w} = \frac{(1-\alpha)\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}}\frac{\partial p}{\partial \bar{v}_j}\hat{y}_q\hat{e}_q}{|\Theta|} > 0$

and from equation (66) it follows that $p_{j\bar{v}}^{w} > 0$.

Changes in w are derived regarding equation (23):

$\frac{\partial w}{\partial \bar{v}_j} = \frac{\partial p}{\partial \bar{v}_j} - [\frac{\partial q}{\partial \bar{v}_j} + \alpha\frac{\partial s}{\partial \bar{v}_j}] - c_{v_j v_j}^{n}\hat{v}_{j p_j}\frac{\partial p}{\partial \bar{v}_j} + \frac{\hat{v}_{j p_j}^{2}\frac{\partial p}{\partial \bar{v}_j} - \hat{v}_j\hat{v}_{j p_j p_j}\frac{\partial p}{\partial \bar{v}_j}}{\hat{v}_{j p_j}^{2}}$

$\frac{\partial w}{\partial \bar{v}_j} = \frac{\partial p}{\partial \bar{v}_j}\beta - [\frac{\partial q}{\partial \bar{v}_j} + \alpha\frac{\partial s}{\partial \bar{v}_j}] < 0$

Assuming that $\beta = [1 - c_{v_j v_j}^{n}\hat{v}_{j p_j} + \frac{\hat{v}_{j p_j}^{2} - \hat{v}_j\hat{v}_{j p_j p_j}}{\hat{v}_{j p_j}^{2}}] > 0$.

III. Incentive Mechanism

Due to his Stackelberg leader position distributor j takes into account equations (25) and, hence, maximizes equation (26) which results in

$0 = \hat{v}_j(p_j, \sigma_j) + (p_j - q - \alpha s - c_{v_j}^{n} - w)\frac{\partial p}{\partial \bar{v}_j} - \bar{d}\sigma_j\frac{\partial \hat{i}_j}{\partial p_j}$

and $0 \neq (p_j - q - \alpha s - c_{v_j}^{n} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d}\ \hat{i} - \bar{d}\ \sigma_j\frac{\partial \hat{i}}{\partial \sigma_j}$

IV. Cost Recovery

IV.1 Distributor j acts according to

$$\max_{p_j}(p_j - q - \alpha s)\hat{v}_j(p_j) - c^n(\hat{v}_j) + w(\bar{v}_j - \hat{v}_j(p_j)) + b(\bar{v}_j - \hat{v}_j(p_j)) \tag{69}$$

which results in $p_j + \frac{\hat{v}_j}{\frac{\partial \bar{v}_j}{\partial p_j}} = q + \alpha s + c_{v_j}^{n} + (w + b)$.

changes in prices p, q, s, and z with respect to b are defined through equations (29) to (32) and changes in w are defined through equations (28) which leads to

$$\Sigma_{j=1}^{n}\frac{\partial p}{\partial \bar{v}_j} = \Sigma_{j=1}^{n}\frac{0}{\hat{v}_{j_{p_j}}} = 0 \tag{70}$$

From (18) to (20) we can derive the effects of changes in $\bar{v}$ on prices q, s and z:

$$\Theta \begin{pmatrix} q_b^w \\ s_b^w \\ z_b^w \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \tag{71}$$

where $\Theta = \begin{pmatrix} \hat{y}_q & \hat{y}_q & 0 \\ \hat{x}_q & 0 & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix} > 0$ according to equation (68).

[p] Due to the assumption that $(1-\alpha)\hat{y}_q < \alpha\hat{x}_q$.

IV.2 From (68) and (71) it follows that
$q^w_{\bar{v}} = \frac{0}{|\Theta|} = 0$

$s^w_{\bar{v}} = \frac{0}{|\Theta|} = 0$

$z^w_{\bar{v}} = \frac{0}{|\Theta|} = 0$

and from equation (70) it follows that $p^w_{j_b} = 0$.

Changes in w are derived regarding equation (28):
$\frac{\partial w}{\partial b} = -1$

V. Price Caps

V.1 Households act according to (25) which results in
End-users:
Changes in p:

$$\Omega \begin{pmatrix} \hat{v}_{j_{\sigma_j}} \\ \hat{i}_{j_{\sigma_j}} \end{pmatrix} = \begin{pmatrix} 0 \\ -\bar{d} \end{pmatrix} \tag{72}$$

where $\Omega = \begin{pmatrix} U_{vv} & U_{vi} \\ U_{iv} & U_{ii} \end{pmatrix}$.
According to equations (58) it follows that $|\Omega| > 0$.
From (58) and (72) it follows that

$$\hat{v}_{j_{\sigma_j}} = \frac{\bar{d} U_{vi}}{|\Omega|} < 0 \tag{73}$$

$$\hat{i}_{j_{\sigma_j}} = -\frac{\bar{d} U_{vv}}{|\Omega|} > 0 \tag{74}$$

V.2 Maximizing equations (37) results in

$0 = \hat{v}_j(p_j, \sigma_j) + (p_j - q - \alpha s - c^n_{v_j} - w - t)\frac{\partial p}{\partial \bar{v}_j} - \bar{d}\sigma_j \frac{\partial \hat{i}_j}{\partial p_j}$
and $0 = (p_j - q - \alpha s - c^n_{v_j} - w - t)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \bar{d}\, \hat{i} - \bar{d}\, \sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}$

assuming that $t > p_j - q - \alpha s - c^n_{v_j} - w$.

VI. Partial integration of End-users into WCTS

VI.1 From equations (41) to (44) and equations (45) and (46) the effects on prices q, s, z, w, p_k and p_j can be inferred.
With respect to changes in prices p_k equations (44) render

$$\Sigma^K_{k=1} \frac{\partial p_k}{\partial \bar{v}_k} = \Sigma^K_{k=1} \frac{1}{\hat{v}_{k p_k}} < 0. \tag{75}$$

With respect to changes in $q, s,$ and z equations (41) to (43) render

$$\Gamma \begin{pmatrix} q^w_{\bar{v}} \\ s^w_{\bar{v}} \\ z^w_{\bar{v}} \end{pmatrix} = \begin{pmatrix} \alpha \Sigma^K_{k=1} \hat{v}_{k p_k} \frac{\partial p_k}{\partial \bar{v}_k} \\ (1-\alpha)\Sigma^K_{k=1} \hat{v}_{k p_k} \frac{\partial p_k}{\partial \bar{v}_k} \\ 0 \end{pmatrix} \tag{76}$$

where $\Gamma = \begin{pmatrix} \hat{y}_q - \alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi} & \hat{y}_q - \alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi} & 0 \\ \hat{x}_q - (1-\alpha)\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi} & -(1-\alpha)\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi} & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix}$,

due to the fact that equations (46) render, with respect to changes in p_j

$$\frac{\partial p_j}{\partial \bar{v}} = \frac{\frac{\partial q}{\partial \bar{v}} + \alpha\frac{\partial s}{\partial \bar{v}}}{\varpi} \tag{77}$$

with $\varpi = [1 - c^n_{v_j v_j}\hat{v}_{j p_j} + \frac{\hat{v}^2_{j_{p_j}} - \hat{v}_j\hat{v}_{j p_j p_j}}{\hat{v}^2_{j_{p_j}}}] > 0$.

Due to assumption of concavity and due to equations (3), (7), and (51), it can be inferred that

$$|\Gamma| = (\alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi} - \hat{y}_q)(\hat{x}_q\hat{e}_z - \hat{x}_z\hat{e}_q) > 0 \tag{78}$$

VI.2 From (76) and (78) it follows that

$$q^w_{\bar{v}} = \frac{-\alpha\ (1-\alpha)\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\Sigma_{k=1}^K\hat{v}_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k}\hat{e}_z - (1-\alpha)(\hat{y}_q - \alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi})\Sigma_{k=1}^K\hat{v}_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k}\hat{e}_z}{|\Gamma|} > 0$$

$$s^w_{\bar{v}} = \frac{\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{\partial p}{\partial \bar{v}_j}\frac{1}{\varpi}[\hat{y}_q\hat{e}_z(1-\alpha) - \alpha(\hat{x}_q\hat{e}_z - \hat{e}_q\hat{x}_z)]}{|\Gamma|} \gtrless 0$$

$$z^w_{\bar{v}} = \frac{(1-\alpha)\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{\partial p}{\partial \bar{v}_j}\frac{1}{\varpi}\hat{y}_q\hat{e}_q}{|\Gamma|} > 0$$

and from equations (46) and (77) it follows that $p^w_{j\bar{v}} > 0$.

Changes in w are derived regarding equation (45):

$$\frac{\partial w}{\partial \bar{v}_k} = \frac{\partial p_k}{\partial \bar{v}_k} - [\frac{\partial q}{\partial \bar{v}_k} + \alpha\frac{\partial s}{\partial \bar{v}_k}] - c^n_{v_k v_k}\hat{v}_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k} + \frac{\hat{v}^2_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k} - \hat{v}_k\hat{v}_{k p_k p_k}\frac{\partial p_k}{\partial \bar{v}_k}}{\hat{v}^2_{k p_k}}$$

$$\frac{\partial w}{\partial \bar{v}_k} = \frac{\partial p_k}{\partial \bar{v}_k}\zeta - [\frac{\partial q}{\partial \bar{v}_k} + \alpha\frac{\partial s}{\partial \bar{v}_k}] < 0$$

Assuming that $\zeta = [1 - c^n_{v_k v_k}\hat{v}_{k p_k} + \frac{\hat{v}^2_{k p_k} - \hat{v}_k\hat{v}_{k p_k p_k}}{\hat{v}^2_{k p_k}}] > 0$.

VI.3 *Inserting* $p^w_{j\bar{v}} > 0$ *into* $\frac{\partial\Sigma_{j=1}^{(n-K)}\hat{v}_j(p^w_j)}{\partial\Sigma_{k=1}^K\bar{v}_k}$ *yields:*

$$\frac{\partial\Sigma_{j=1}^{(n-K)}\hat{v}_j(p^w_j)}{\partial\Sigma_{k=1}^K\bar{v}_k} = \Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{\partial p_j}{\partial\Sigma_{k=1}^K\bar{v}_k} \lesseqgtr -1$$

regarding equations (77) this leads to

$$\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{\frac{\partial q}{\partial \bar{v}} + \alpha\frac{\partial s}{\partial \bar{v}}}{\varpi} \lesseqgtr -1$$

$$\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\frac{1}{\varpi}[\frac{\Sigma_{k=1}^K\hat{v}_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k}(\alpha^2(\hat{x}_z\hat{e}_q - \hat{x}_q\hat{e}_z) - (1-\alpha)^2\hat{y}_q\hat{e}_z)}{\Gamma}] \lesseqgtr -1$$

which leads to

$$\frac{1}{\varpi}[-\alpha^2(\hat{x}_z\hat{e}_q - \hat{x}_q\hat{e}_z) - (1-\alpha)^2\hat{y}_q\hat{e}_z)] \gtrless \frac{(\alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}} - \hat{y}_q)(\hat{x}_z\hat{e}_q - \hat{x}_q\hat{e}_z)}{\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\Sigma_{k=1}^K\hat{v}_{k p_k}\frac{\partial p_k}{\partial \bar{v}_k}}$$

and, since $\frac{1}{\varpi}[-\alpha^2(\hat{x}_z\hat{e}_q - \hat{x}_q\hat{e}_z) - (1-\alpha)^2\hat{y}_q\hat{e}_z)] > 0$ and $\frac{(\alpha\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}} - \hat{y}_q)(\hat{x}_z\hat{e}_q - \hat{x}_q\hat{e}_z)}{\Sigma_{j=1}^{(n-K)}\hat{v}_{j_{p_j}}\Sigma_{k=1}^{K}\hat{v}_{k_{p_k}}\frac{\partial p_k}{\partial \bar{v}_k}} < 0$ it is clear that

$$\frac{\partial\Sigma_{j=1}^{(n-K)}\hat{v}_j(p_j^w)}{\partial\Sigma_{k=1}^{K}\bar{v}_k} < -1 \tag{79}$$

VII. Is Less still more

VII.1 From (47) to (50) we can derive the effects of changes in e:

$$\Gamma \begin{pmatrix} q_{\bar{e}}^l \\ s_{\bar{e}}^l \\ z_{\bar{e}}^l \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \tag{80}$$

where $|\Gamma| > 0$ as shown in equation (78).

VII.2 From (47) to (50) and (80) it follows that

$q_{\bar{e}}^l = \frac{(\hat{y}_q - \alpha^2\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}})\hat{x}_z}{|\Gamma|} < 0$

$s_{\bar{e}}^l = \frac{\hat{x}_z(-(\hat{y}_q - \alpha\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}})\hat{x}_z}{|\Gamma|} > 0$

$z_{\bar{e}}^l = \frac{\hat{x}_q(\alpha^2\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}} - \hat{y}_q) + (1-\alpha)^2\hat{y}_q\Sigma_{j=1}^{n}\hat{v}_{j_{p_j}}}{|\Gamma|} < 0$

and according to equations (50) it follows that
$p_{\bar{e}}^l < 0$

VII.3 *Regarding I:* It follows from (6) and (7) that

$$\hat{I}_{\bar{e}} = \hat{I}_q\frac{\partial q}{\partial \bar{e}} + \hat{I}_z\frac{\partial z}{\partial \bar{e}} < 0 \tag{81}$$

Regarding i:

$$\Omega \begin{pmatrix} \hat{v}_{\bar{e}} \\ \hat{i}_{\bar{e}} \end{pmatrix} = \begin{pmatrix} p_{\bar{e}}^d \\ 0 \end{pmatrix} \tag{82}$$

It follows from equations (58) and (82) that
$v_{\bar{e}} = \frac{U_{ii}p_{\bar{e}}^l}{|\Omega|} > 0$
$i_{\bar{e}} = -\frac{U_{iv}p_{\bar{e}}^l}{|\Omega|} < 0$, as i and v are substitutes

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